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(54) **ASYMMETRIC DELAY CIRCUIT**

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(71) Applicant: **MStar Semiconductor, Inc.**, Hsinchu Hsien (TW)

(72) Inventors: **Huimin Tsai**, Hsinchu Hsien (TW);
Yu-Min Yeh, Hsinchu Hsien (TW)

(73) Assignee: **MStar Semiconductor, Inc.**, Hsinchu Hsien (TW)

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H03K 5/159 (2006.01)
H03K 5/04 (2006.01)

(52) **U.S. Cl.**

CPC . **H03K 5/159** (2013.01); **H03K 5/04** (2013.01)

(58) **Field of Classification Search**

USPC 327/263, 264, 261, 294, 172-176
See application file for complete search history.

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Primary Examiner — Lincoln Donovan

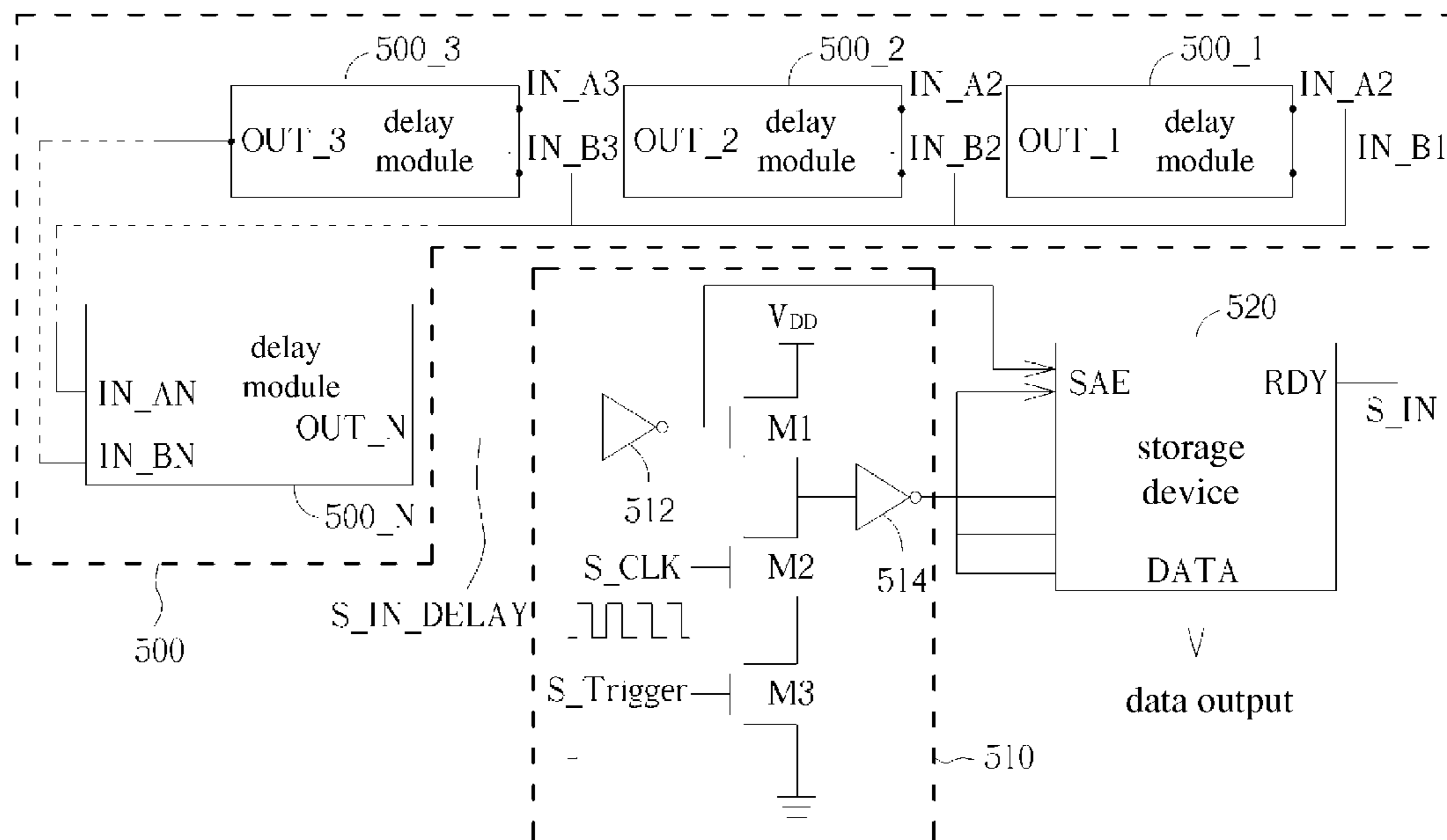
Assistant Examiner — Thomas Skibinski

(74) Attorney, Agent, or Firm — Edell, Shapiro & Finnan, LLC

(57) **ABSTRACT**

A delay circuit for receiving an input signal and generating a delayed output signal. The delay circuit includes a first delay module and a second delay module. The first delay module includes a first delay unit for generating a first delayed signal according to an input signal and a first logic unit, coupled to the first delay unit, for generating a first delayed output signal according to the first delayed signal and the input signal. The second delay module includes a second delay unit for generating a second delayed signal according to the first delayed output signal and a second logic unit, coupled to the second delay unit, for generating the delayed output signal according to the second delayed signal and the input signal.

6 Claims, 8 Drawing Sheets



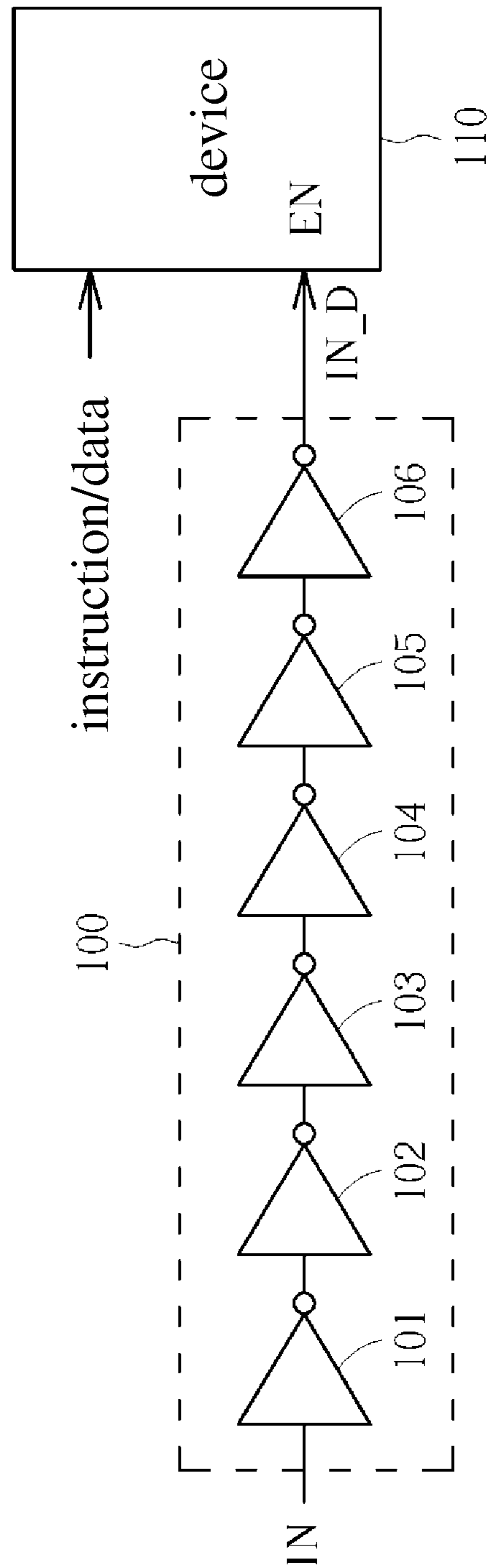


FIG. 1 (PRIOR ART)

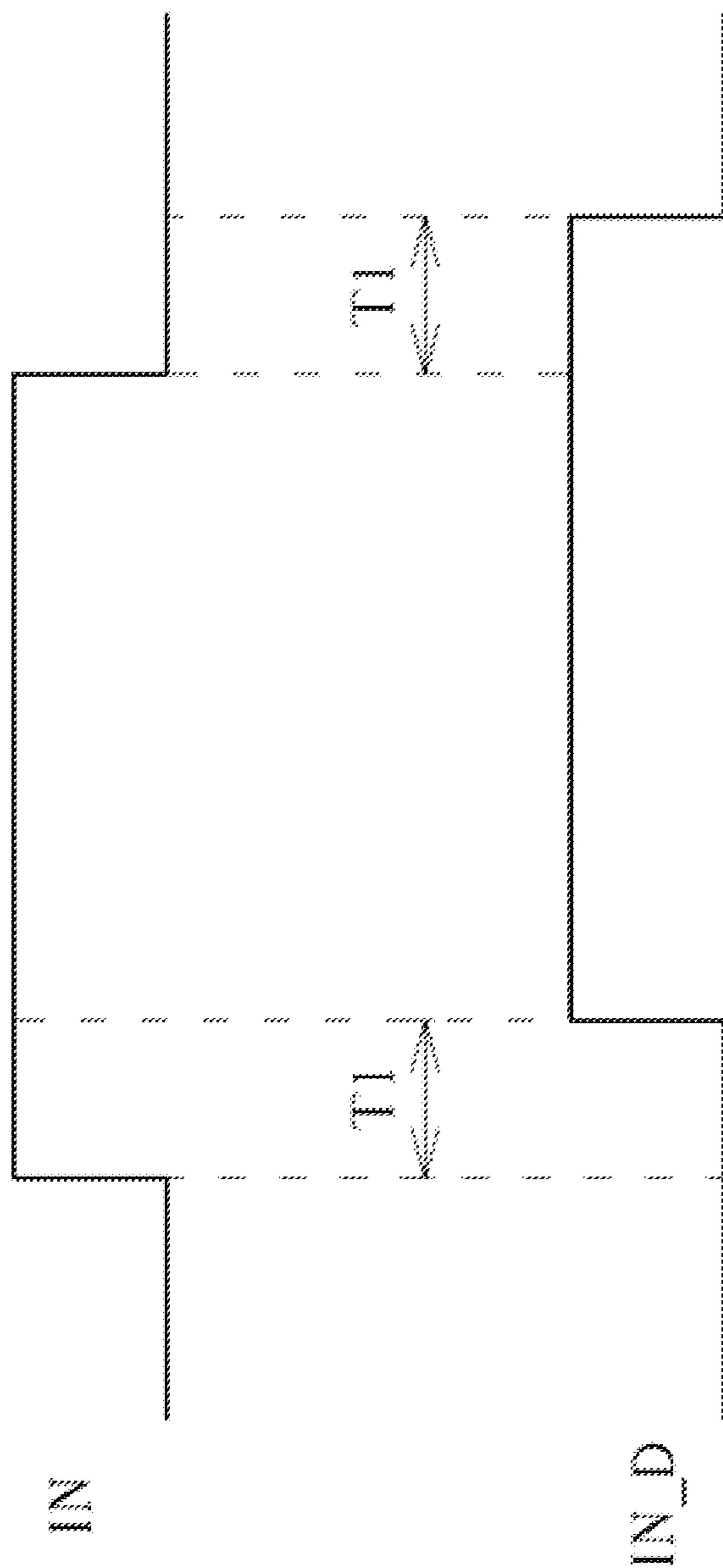


FIG. 2 (PRIOR ART)

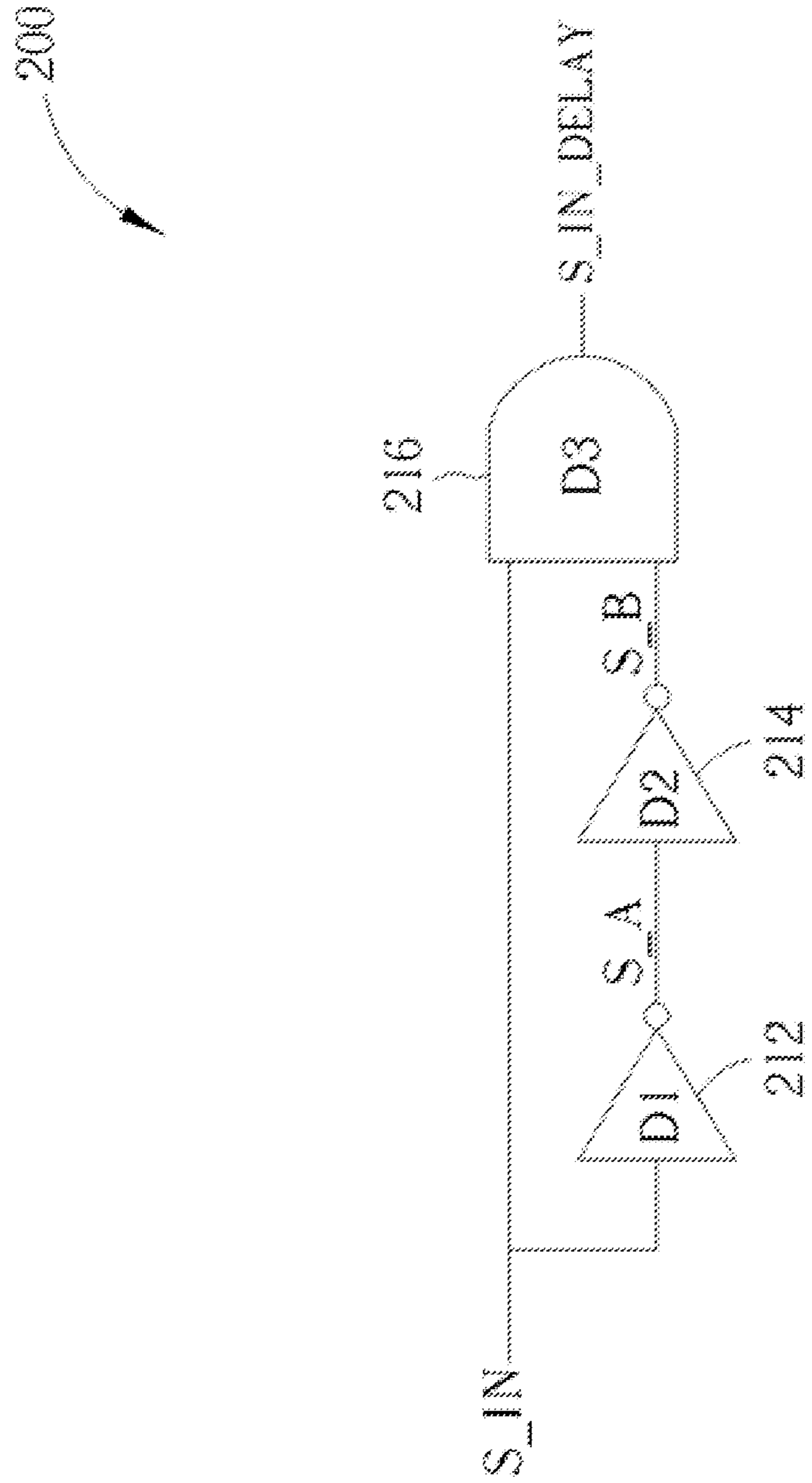


FIG. 3

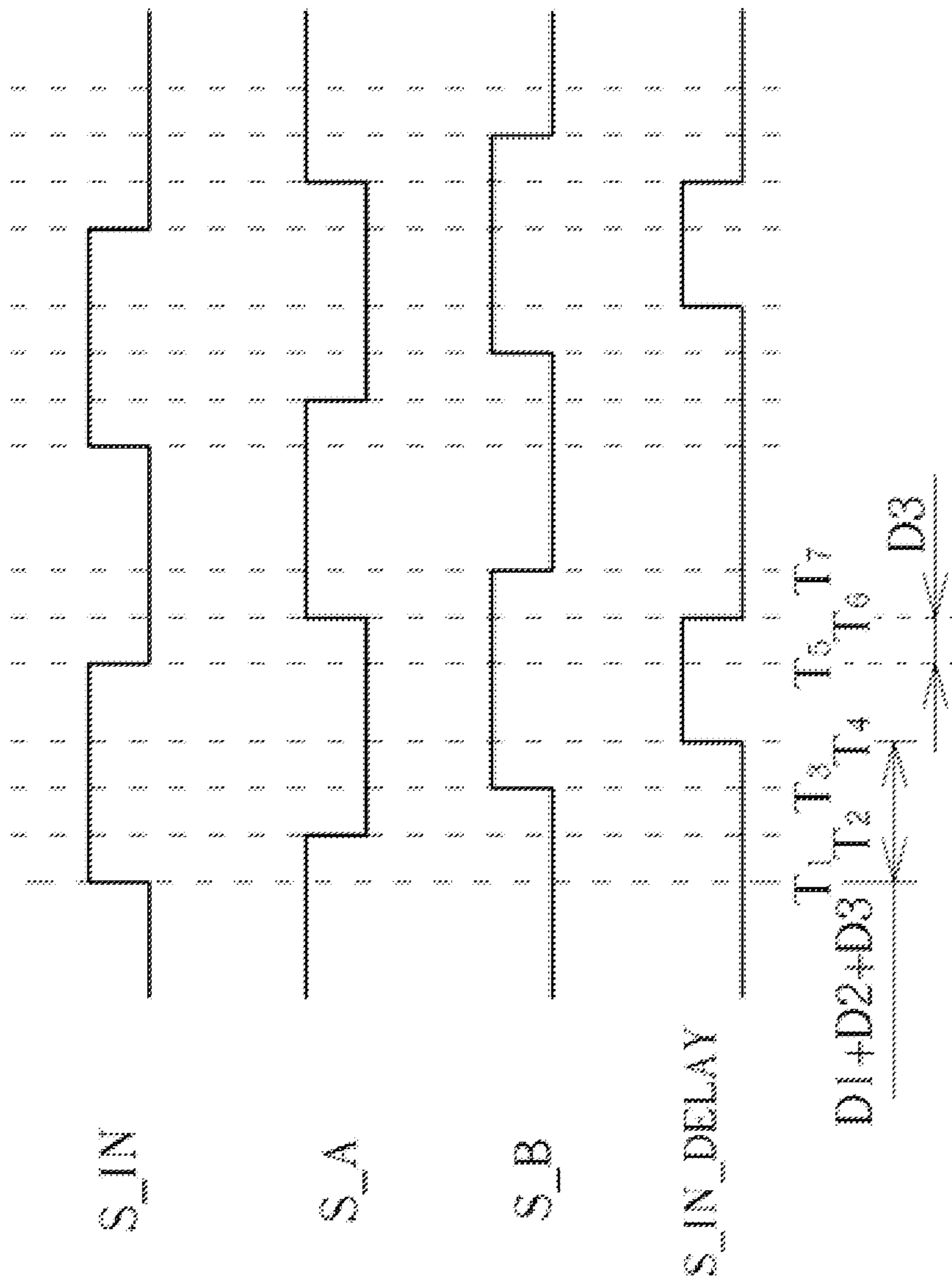


FIG. 4

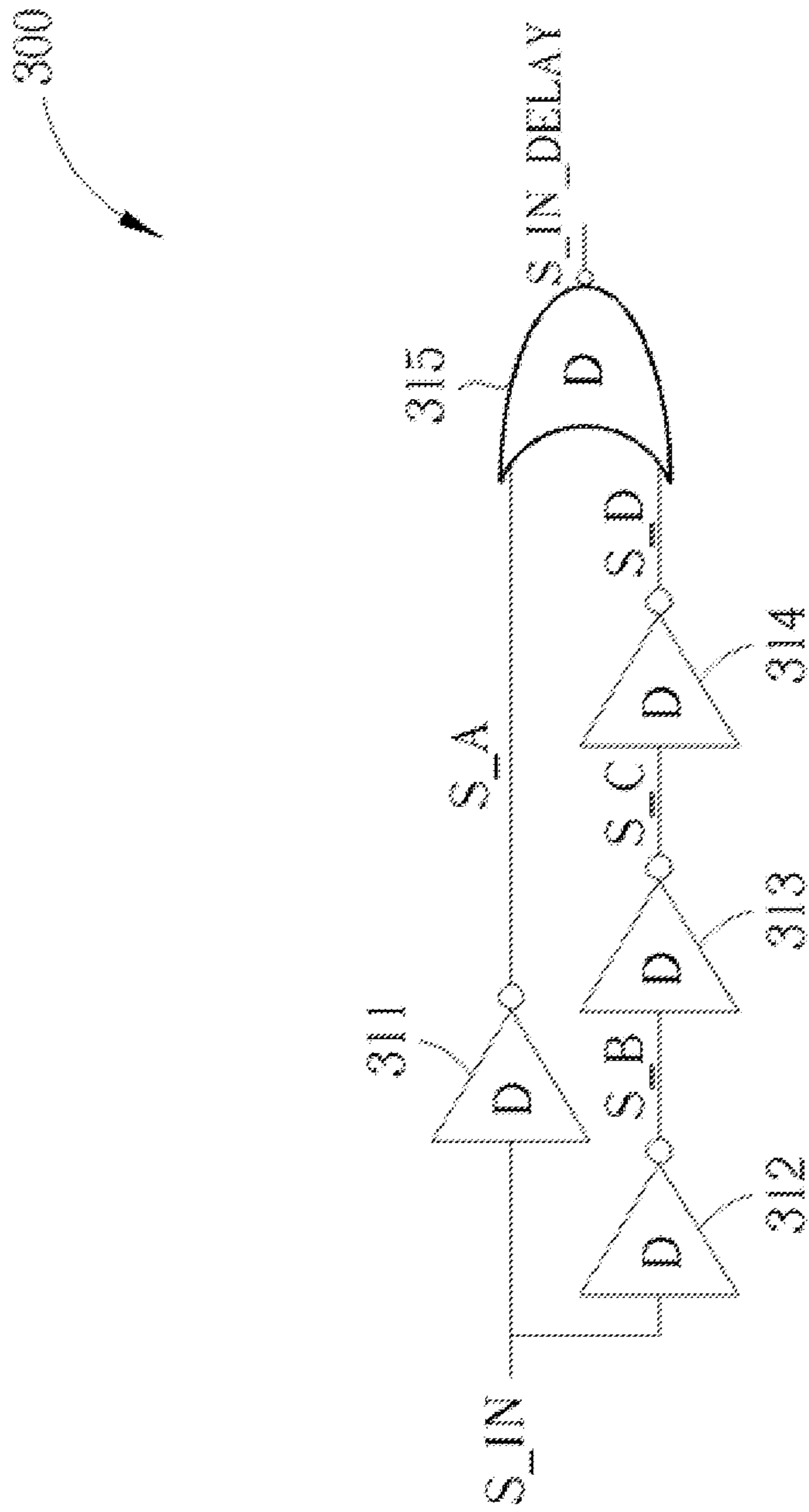


FIG. 5

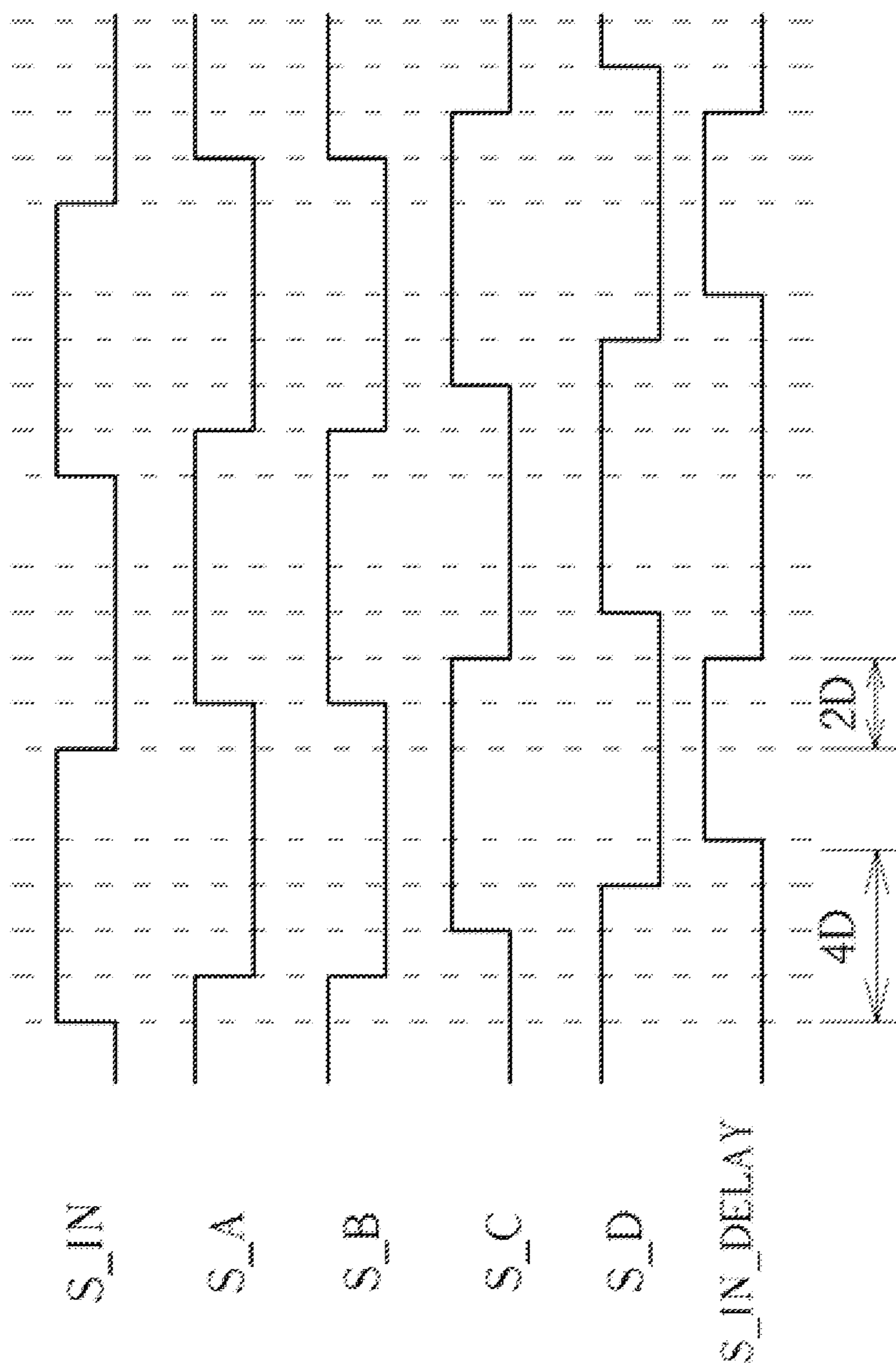


FIG. 6

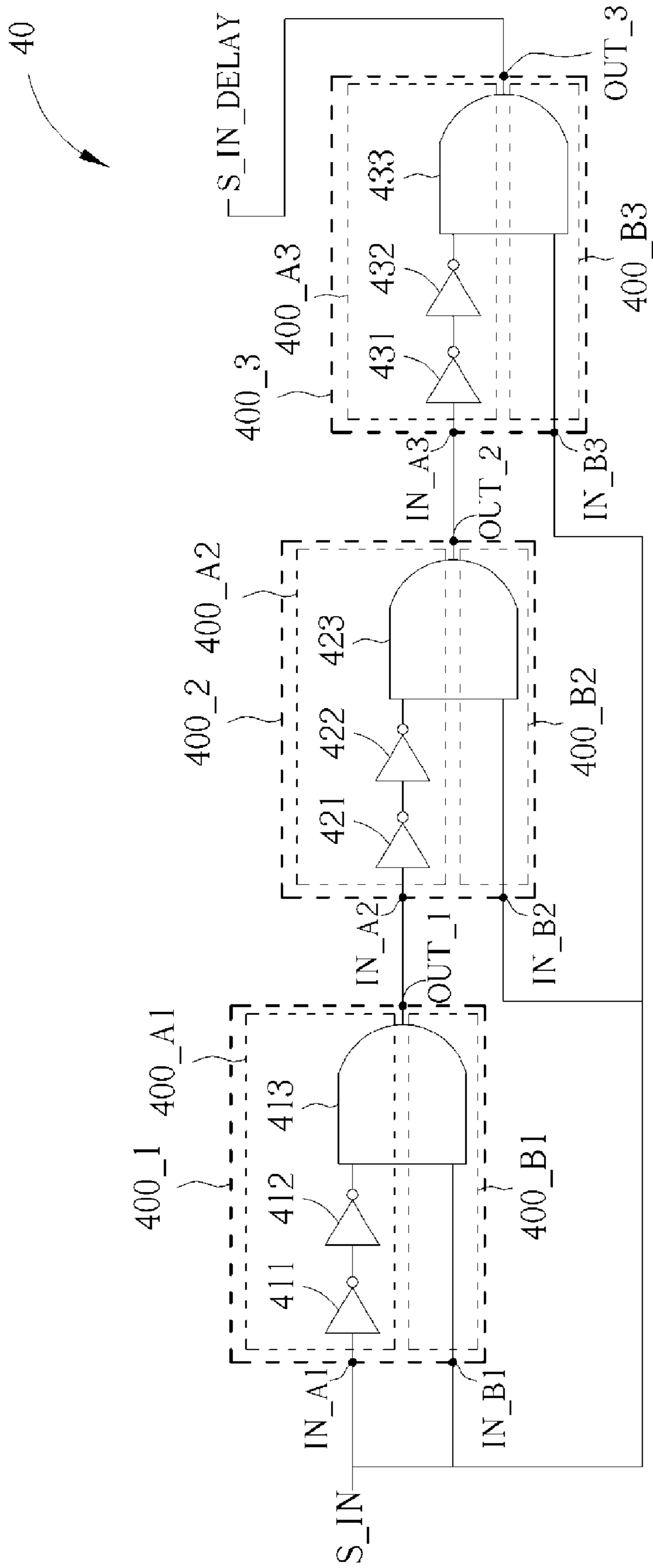


FIG. 7

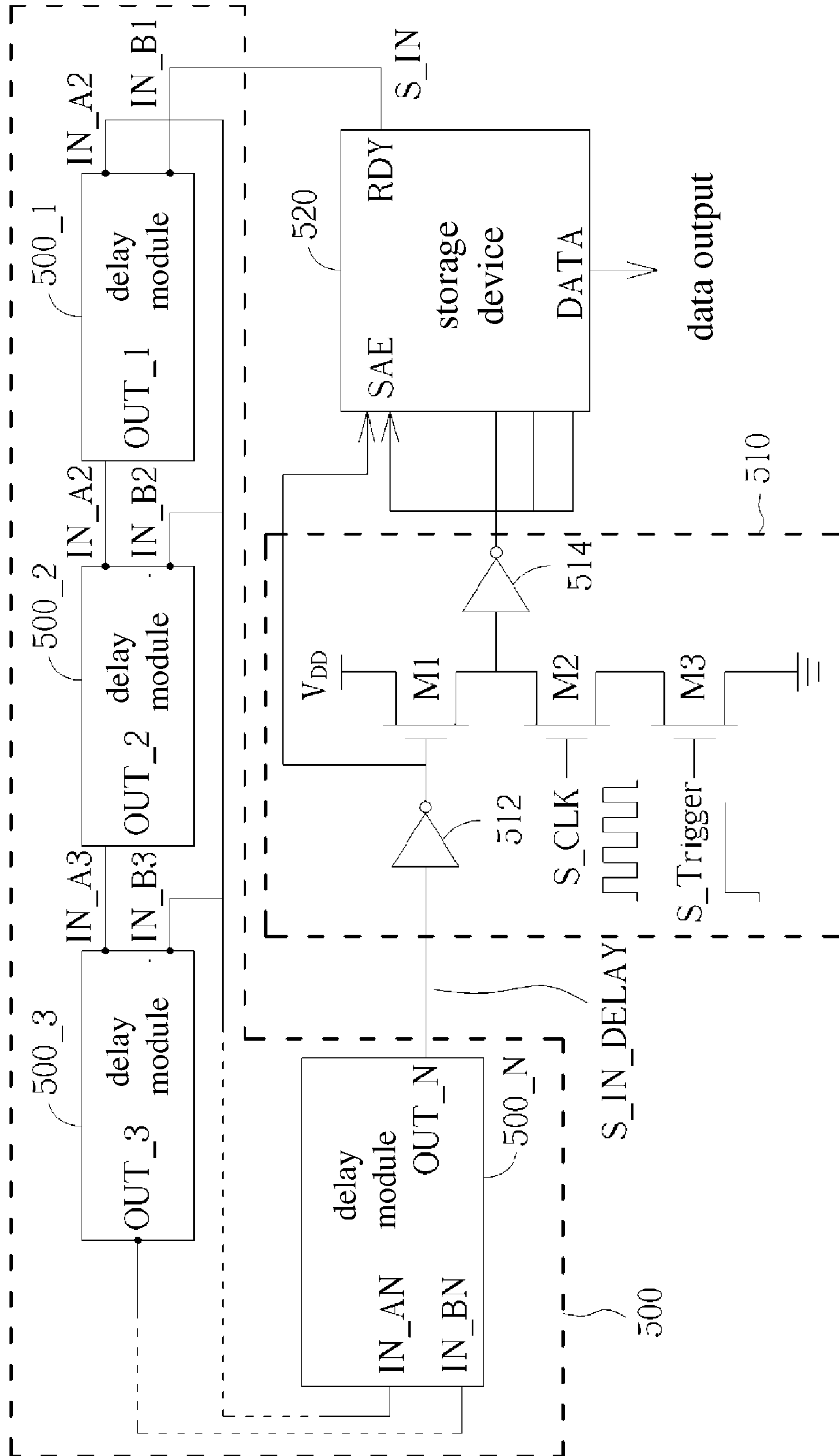


FIG. 8

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ASYMMETRIC DELAY CIRCUIT

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority under 35 U.S.C 119 to Taiwan patent application, TW101139083, filed on Oct. 23, 2012, the disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to digital circuitry, and more particularly, to a delay circuit having asymmetric delay times.

2. Description of the Prior Art

In the field of digital circuitry, it is very important to control timing synchronization. General speaking, many digital circuits are controlled by an enable signal. For example, in case of memory access, in addition to a memory address to be accessed, control logic is required to generate an enable signal to an associated memory controller. Upon receiving the enable signal, the memory controller starts to access the addressed memory.

Normally, a memory controller is activated to perform an access operation if the enable signal is raised by control logic. Conversely, the memory controller stops an access operation if the enable signal is pulled down. When the enable signal is raised again by control logic, memory controller begins a next access operation. In order to prevent error operations, control logic and/or memory are usually required to wait for a predetermined amount of time to enable states of the internal circuit components to stabilize before beginning to perform a next access operation.

For this purpose, a traditional delay circuit **100** shown in FIG. 1 is adopted in the prior art for delaying an enable signal IN for a device **110** to be activated. As a result, activation timing of the device **110** is determined by a delayed enable signal IN_D. Please also refer to FIG. 2, juxtaposes the enable signal IN, and a voltage level of the delayed enable signal IN_D transiting from low to high delays for a delay time T1, which is caused by delay elements **101** to **106**.

Although the delay circuit **100** guarantees that the device **100** performs a next round operation after states of internal circuits are stabilized, such a circuit wastes too much time in waiting. This is because the design of the delay circuit **100** delays the same time no matter whether the enable signal is raised or pulled down. However, in most applications, only where the enable signal IN is raised or transits from low to high voltage level, is it necessary to wait for states of circuits to stabilize. In other words, there is no need to introduce delay in the case where the enable signal IN falls or transits from a high to low voltage level. Nevertheless, as shown in FIG. 2, the delay circuit **100** shown in FIG. 1 delays the enable signal T1 time when the enable signal IN transits from a high to low voltage level. As a result, the circuit delays too much in continuous operations of the device **100** and degrades operating efficiency.

SUMMARY OF THE INVENTION

Accordingly, the present invention provides a delay circuit having asymmetric delay times. The delay circuit of the present invention provides different delay effects for a rising transition and a falling transition of an input signal.

One embodiment of the present invention provides a delay circuit for receiving an input signal and generating a delayed

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output signal. The delay circuit comprises a first delay module and a second delay module. The first delay module comprises a first delay unit for generating a first delayed signal according to an input signal and a first logic unit, coupled to the first delay unit, for generating a first delayed output signal according to the first delayed signal and the input signal. The second delay module comprises a second delay unit for generating a second delayed signal according to the first delayed output signal and a second logic unit, coupled to the second delay unit, for generating the delayed output signal according to the second delayed signal and the input signal.

As a consequence of such a configuration, in case the input signal is raised for activating a specified device controlled by the input signal, the delay circuit of the present invention can provide longer delay time for the specified device until internal components of the specified device are stabilized. For deactivating operation of the specified device, the delay circuit of the present invention can provide a shorter delay time for the input signal. Hence the falling transition of the input signal can be sent quickly to the specified device for deactivation.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a diagram of a traditional delay circuit.

FIG. 2 depicts a timing diagram of a delayed signal with respect to an input signal generated by the traditional delay circuit shown in FIG. 1.

FIG. 3 illustrates a schematic diagram of a delay module according to an embodiment of the present invention.

FIG. 4 illustrates a timing diagram of signals at multiple points of the delay module shown in FIG. 3.

FIG. 5 illustrates a schematic diagram of a delay module according to another embodiment of the present invention.

FIG. 6 illustrates a timing diagram of signals at multiple points of the delay module shown in FIG. 5.

FIG. 7 illustrates a schematic diagram of a delay circuit according to another embodiment of the present invention.

FIG. 8 depicts an application including a delay circuit in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In order to solve the problem addressed in the prior art, multiple small delay modules are used to replace traditional delay circuits consisting of many delay elements. Reference is made to FIG. 3 and FIG. 4, which show a schematic diagram of a delay module in accordance with an embodiment of the present invention and a timing diagram with respect to signals at multiple points in the delay module, respectively. At timing point T₁, an input signal S_IN rises. Since state of the input signal S_IN is at low level prior to timing point T₁, output signal S_IN_DELAY of an AND gate **216** is at low level. When signal S_IN rises at timing point T₁, an output signal S_A of a delay unit **212** transits from high to low level until timing point T₂ due to delay effect of the delay unit **212** itself. Similarly, an output signal S_B of a delay unit **214** transits its state at timing point T₃ due to delay effect of the delay unit **214** itself. Since both inputs of the AND gate **216** are at high level at this timing point, an output signal S_IN_DELAY of the AND gate **216** transits from initial low level to high level in response to the rising of input signal S_IN. Moreover, because of delay effect of the AND gate **216**, the output signal S_IN_DELAY rises at timing point T₄ after timing point T₃. Thus, in the case where the input signal S_IN rises, total delay time caused by the delay module **200** is

$(T_4 - T_1)$ which equals to the sum (in unit of time) of delay effects D1, D2, and D3 caused by the delay unit **212**, **214**, and the AND gate **216**, respectively. However, in the case where the input signal S_IN falls, the delay module **200** provides a totally different delay effect.

Reference is again made to FIG. **3** and FIG. **4**. At timing point T_5 , the input signal S_IN falls. Since both inputs of the AND gate **216** are at a high level prior to timing point T_5 , the output signal S_IN_DELAY is at a high level. At timing point T_5 , one input of the AND gate **216** receives the input signal S_IN having low level. Consequently, the output signal S_IN_DELAY of the AND gate **216** transits from high to low level quickly. Considering delay effect of the AND gate **216** itself, the output signal S_IN_DELAY of the AND gate **216** falls at timing point T_6 after timing point T_5 . Thus, total delay time caused by the delay module **200** is $(T_6 - T_5)$ which is equivalent to delay effect D3 of the AND gate **216** itself. As a result, by using the delay module provided by the present invention, different delay times for rising delay and falling delay are generated. Comparing with the traditional delay circuit **100** having the same rising delay and falling delay time, the delay module in the present invention largely decreases the falling delay. Taking the traditional delay circuit **100** as an example, both of the rising delay and the falling delay are caused by total delay effect $6 \cdot D$ of six delay elements **101** to **106**. Alternatively, if implementing the traditional delay circuit **100** by two of delay module **200** shown in FIG. **3**, it generates total delay effect $6 \cdot D$ corresponding to the raising delay by assuming $(D1 = D2 = D3 = D)$, in unit of time). For falling delay, the delay circuit embodied the delay module provided by the present invention generates merely delay effect D which is a sixth of total delay effect of traditional delay circuit **100**. Hence, the operating speed can be largely increased if realizing the delay circuit by the delay module provided by the present invention.

In addition to the fore-mentioned embodiment, the delay module of the present invention may be realized by other implementations. Reference is made to FIG. **5** and FIG. **6** which show a schematic diagram of a delay module in accordance with another embodiment of the present invention and a timing diagram of the delay module, respectively. According to FIG. **5**, outputting a delayed output signal S_IN_DELAY, a delay module **300** generates a total rising delay $4D$ caused by delay units **312**, **313**, and **314** as well as NOR gate **315** (assuming delay effect caused by each component is equal) in response to raising of an input signal S_IN. Additionally, in response to falling of the input signal S_IN, the delayed output signal S_IN_DELAY is generated and delayed a total falling delay $2D$ caused by the delay unit **311** and the NOR gate **315**.

From the two embodiments described above, those skilled in the art will appreciate that the delay module in the present invention may be realized by any other combinations of circuit equivalent to performing AND operation on both input signals. For example, the delay module **200** performs AND operation on the input signal S_IN. Although the delay module **300** performs an inverse operation on the input signal S_IN at first, by utilizing a NOR operation performed by the NOR gate **325** on the inversed signal, the output signal substantially equals to the outcome of performing AND operation on the input signal S_IN. In summary, the number and types of logic gates as well as the number of delay units described in the instant description and figures should not be construed as limiting the present invention. Furthermore, although the delay units shown in the figures are represented

by inverters, any other circuits having delay effect may be used to implement delay units in other embodiments according to the present invention.

The delay module in the present invention may be further combined as a delay circuit **40** as shown in FIG. **7** used to delay an input signal S_IN. Structure of the delay circuit **40** shown in FIG. **7** comprises delay modules **400_1** to **400_3**. Each delay module comprises multiple delay units and a logic gate. Each delay module has input ends IN_A1 to IN_A3 and IN_B1 to IN_B3 as well as output ends OUT_1 to OUT_3. These delay modules **400_1** to **400_3** are interconnected in series. The delay modules **400_1** to **400_3** comprises first signal paths **400_A1** to **400_A3** and second signal paths **400_B1** to **400_B3**, respectively, for providing different delay effects corresponding to rising and falling of the input signal S_IN. Taking the delay module **400_1** as an example, the first signal path **400_A1** is a path from the input end IN_A1 to the output end OUT_1 through delay units **411**, **412**, and logic gate **413**. The second signal path **400_B1** is a path from the input end IN_B1 to the output end OUT_1 via the logic gate **413**.

Except for the last stage of delay module **400_3**, the output end of each delay module is coupled to the input end of delay module in next stage. Similarly, except for the first stage of delay module **400_1**, the input end of each delay module receives output of delay module in a previous stage in addition to the input signal S_IN. Based on such a configuration, in the case where the input signal S_IN rises, the delay circuit **40** generates the delayed output signal S_IN_DELAY in total of delay effects $T1 + T2 + T3$ of the first signal path **400_A1** to **400_A3** of the delay modules **400_1** to **400_3**. In the case where the input signal S_IN falls, the delay circuit **40** generates the delayed output signal S_IN_DELAY according to the delay effect T3 of the second signal path **400_B3** of the last stage of delay module **400_3**. It is noted that although the descriptions and figures above utilize the delay module shown in FIG. **3** to implement the delay circuit **40**, it may utilize the delay module shown in FIG. **5** to implement the delay circuit **40** in other embodiments of the present invention.

With respect to real applications of the delay circuit in accordance with the present invention, the embodiment shown in FIG. **8** may be referenced. FIG. **8** depicts an access operation to a storage device **520**. The activating and deactivating timings of such an access operation are determined by an enable signal generator circuit **510**. In the case where a signal at a connection port SAE of the storage device **520** is raised, a sensing amplifier (not shown in FIG. **8**) of the storage device **520** amplifies the signal read from memory units of the storage device **520** and outputs the amplified signal to an output port DATA as a data access operation. When the data access operation is complete, an output port RDY generates a falling signal to notify the enable signal generator circuit **510** that the data read operation is finished. The storage device **520** is then ready for a next access operation.

Control logic comprising transistors M1, M2, and M3 is used to determine when to raise the signal at the input port SAE for the access operation according to the output signal S_IN of the output port RDY, a clock signal S_CLK, and a trigger signal S_Trigger. In case the signal at the input port SAE is raised, the signal of output port RDY is also raised because the storage device is performing the access operation. A delay circuit **500** comprising delay modules **500_1** to **500_N** delays level transition of signal S_IN at the output port RDY in order to generate a delayed output signal S_IN_DELAY to delay the raising of signal S_IN at the output port RDY. The delay prevents output instability of the control

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logic comprising transistors M1, M2, and M3 when a next pulse of the clock signal S_CLK arrives.

Comparing with the signal S_IN at the output port RDY, the delayed output signal S_IN_DELAY generated by the delay circuit 500 is asymmetric in rising delay and falling delay. Therefore, the delay circuit 500 can not only provide sufficient rising delay to prevent output instability of the control logic consisted of transistors M1, M2, and M3 but can also quickly reflect a falling transition to end operation of the storage device 520 when the access operation of the storage device 520 is finished. As a result, the waiting time for next access operation is shortened so latency of continuous operations of the storage device 520 is also decreased and the reading/writing rate of the storage device 520 is elevated. It is noted that although in the description above, the delay circuit in accordance with the present invention is used to shorten the delay time for one way of voltage level transition, specifically, falling transition from high to low level, the present invention is not so limited. By adopting appropriate modifications, e.g., adding inverters, it is possible for the delay circuit provided by the present invention to decrease the delay time of a rising transition of an input signal.

In summary, the delay circuit of the present invention provides different delay effects for a rising transition and falling transition of an input signal. Hence, it is effective to decrease the latency of continuous operations of circuits and to increase performance of circuits.

The above embodiments are only used to illustrate the principles of the present invention, and they should not be construed as to limit the present invention in any way. The above embodiments can be modified by those with ordinary skill in the art without departing from the scope of the present invention as defined in the following appended claims.

What is claimed is:

1. A memory system comprising:

a storage device comprising:

- an input port SAE;
- an output port RDY;
- an output port DATA;

an enable signal generator, coupled to the storage device, for generating an enable signal to the input port SAE; and

a delay circuit, coupled to the storage device and the enable signal generator, for receiving an input signal from the

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output port RDY and generating a delayed output signal to the enable signal generator, wherein the output port RDY signal provides a falling signal to notify the enable signal generator that a data read operation from the storage device is finished, the delay circuit comprising:

a first delay module comprising:

a first delay unit for generating a first delayed signal according to an input signal; and

a first logic unit, coupled to the first delay unit, for generating a first delayed output signal according to the first delayed signal and the input signal; and

a second delay module comprising:

a second delay unit for generating a second delayed signal according to the first delayed output signal; and

a second logic unit, coupled to the second delay unit, for generating the delayed output signal according to the second delayed signal and the input signal,

wherein when the input signal transits from a first state to a second state, the delayed output signal is delayed for a first delay time with respect to the input signal; and when the input signal transits from the second state to the first state, the delayed output signal is delayed for a second delay time with respect to the input signal, the first delay time and the second delay time being different.

2. The delay circuit of claim 1, wherein one of the first delay unit and the second delay unit comprises a plurality of inverters connected in series.

3. The delay circuit of claim 1, wherein one of the first delay module and the second delay module comprises a first signal path and a second signal path, wherein a first signal delay is generated by the first signal path and a second signal delay is generated by the second signal path.

4. The delay circuit of claim 3, wherein the first delay time is determined according to the first signal delays of the first delay module and the second delay module, and the second delay time is determined according to the second signal delays of the first delay module and the second delay module.

5. The delay circuit of claim 1, wherein one of the first logic unit and the second logic unit is an AND gate.

6. The delay circuit of claim 1, wherein one of the first logic unit and the second logic unit is a NOR gate.

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